

Parameterization of Cumulus Convective Cloud Systems in Mesoscale Forecast Models

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LONG-TERM GOALS

The development and improvement of the microphysics parameterization of cumulus convective clouds in mesoscale numerical weather prediction models

OBJECTIVES

Conduct detailed studies of cloud microphysical processes in order to develop a unified parameterization of boundary layer stratocumulus and trade wind cumulus convective clouds. Develop a parameterization of subgrid cloud variability that in combination with the unified parameterization of conversion/sedimentation rates will provide a complete formulation of microphysical processes in convective clouds for use in mesoscale forecast models. Test the parameterization using COAMPS model in simulations of convective cloud systems.

APPROACH

The research is based on the SAMEX large eddy simulation (LES) model with explicit formulation of aerosol and drop size-resolving microphysics. The LES simulations based on observations from field projects will provide datasets necessary for parameterization development. COAMPS simulations based on field projects data will test the parameterization.

WORK COMPLETED

The following tasks have been completed during the 1st year of the project:

1. Previously we developed a novel approach to formulation of cloud parameterizations which is based on integral moments of the cloud drop size distribution. The design and testing of the integral moments approach has been described in a paper published in the Journal of Atmospheric Sciences.
2. The main work focused on the new study of shallow cumulus convective clouds based on the data from the RICO field project. Using the dataset obtained from RICO simulations we developed a new unified parameterization of conversion and sedimentation rates for use in cloud resolving models. The new parameterization was shown to improve prediction of precipitation in

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the case of shallow cumulus clouds, as well as in the case of marine boundary layer stratocumulus.

RESULTS

1. An integral moment approach to parameterization of cloud physics processes

We developed a microphysics parameterization based on integral moments of the full drop size distributions (DSD), as opposed to partial moments approach (sometimes referred to as Kessler-type parameterization) based on the moments integrated separately over the cloud and rain drop portion of the drop spectrum. The approach avoids division of DSDs into cloud and rain drops. This eliminates the problem of defining the threshold between these two categories and subdivision of the physical coagulation process into artificial processes of autoconversion, accretion, and selfcollection. This approach does not assume a prescribed form of the DSD, but employs as model variables full moments which have clear physical meaning: drop concentration and surface area, water content, precipitation flux, and radar reflectivity. These variables can be directly measured and assimilated into the model forecast cycle without intermediate retrievals.

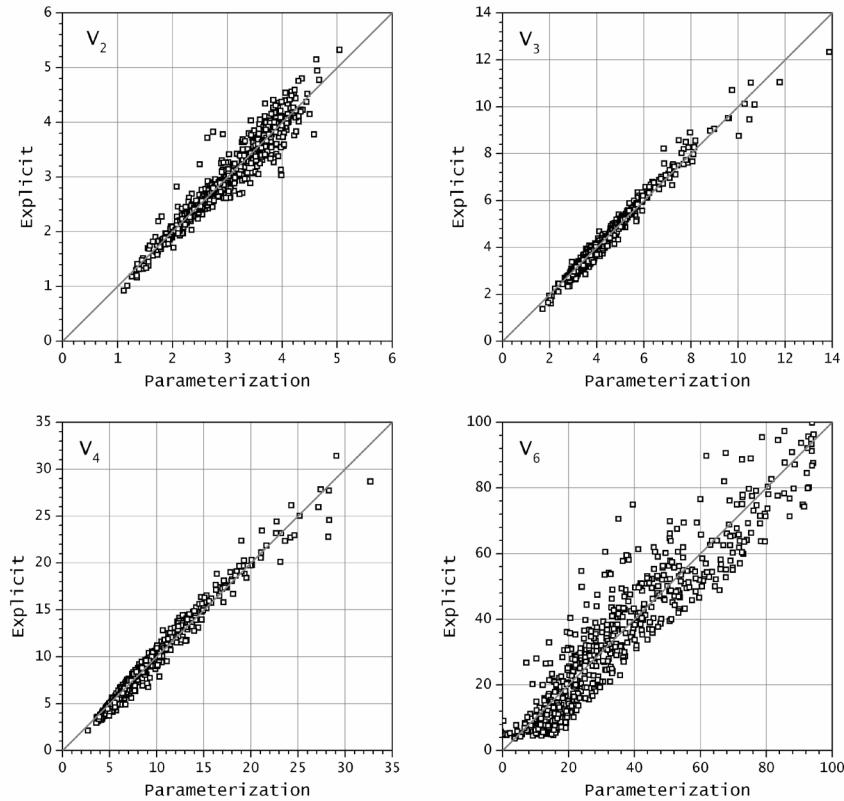


Figure 1. Scatter plots of parameterized values of the weighted fall velocities against the explicit model values. V_2 , V_3 , V_4 , V_6 are fall velocities for the 2nd, 3rd, 4th, and the 6th moments.

The development and testing of the parameterization was made using the CIMMS LES explicit warm rain microphysical model. The condensation-evaporation rate can be calculated explicitly using the drop condensational growth equation. The rate of change for each moment due to coagulation is

determined using regression analysis of the exact coagulation rates from the explicit microphysics LES model. The errors of parameterized expressions are an order of magnitude less than autoconversion rates errors in a conventional Kessler type parameterization. The conversion and sedimentation rates were parameterized in the form of a product of power functions using nonlinear regression analysis to determine exponents of the approximated expressions. Examples of the parameterized sedimentation rates are shown in Fig. 1.

The full moment parameterization has been implemented into the 3D dynamical framework of the CIMMS LES model where the errors of the parameterization were assessed in a realistic setting. The comparison of bulk and explicit microphysics models demonstrated good prediction of both thermodynamical and microphysical parameters of the stratocumulus-topped boundary layer.

2. Formulation of conversion/sedimentation rates in a unified parameterization of shallow cumulus convection and marine boundary layer stratocumulus

The objective of the project is development of a unified microphysical parameterization applicable for shallow cumulus, as well as boundary layer stratocumulus clouds (referred to as Cu parameterization). During the 1st year we developed the core of the parameterization which can be applied for cloud resolving models. Similar to Khairoutdinov and Kogan (2000) parameterization for stratocumulus clouds (referred to as KK parameterization), the Cu parameterization is based on the explicit microphysical LES model as a data source and benchmark for comparison. Like KK, the Cu parameterization partitions the liquid water into a precipitating (rain water) and a nonprecipitating part (cloud water) and solves equations for six prognostic variables which include mixing ratio and number concentration of cloud and rain drops, total mean radius of cloud drops, as well as concentration of CCN (q_c , q_r , N_c , N_r , R_c , n_{ccn}).

The choice of a dataset in parameterization development is important. The dataset should have a parameter range wide enough to cover all possible parameter combinations which may be encountered during a simulation. However, also important for deriving accurate regression approximations is to have a *correct weight of parameter combinations* which realistically represent the balance between heavy, moderate and weak rain producing spectra. The most accurate practical tool for obtaining such dataset is an LES explicit microphysics model. It provides cloud spectra formed under the 3D realistic thermodynamical conditions, and, therefore, contains dynamically balanced spectra corresponding to realistic distributions of cloud/rain liquid water content, drop concentrations, and precipitation intensities. This dynamically balanced dataset is difficult to reproduce by artificially solving the coagulation equation with a prescribed set of initial conditions.

By applying regression analysis to the LES derived dataset, we obtained approximations of the conversion and sedimentation rates valid for the case of cumulus convective clouds. The approximations of accretion and selfcollection rates were especially precise, while the autoconversion and sedimentation rates showed significant spread of data points. Fortunately, the largest errors for autoconversion rates are when they are small and, therefore, they have a lesser effect on precipitation formation. It is speculated that further improvement of autoconversion and sedimentation rates may be possible by applying 3-parameter approximations in the framework of 3-moment microphysical parameterization schemes.

The new bulk microphysics parameterization was incorporated into the dynamical framework of the SAMEX LES model and tested against simulations using explicit microphysics version of the model.

The simulations were based on observations of a shallow cumulus convective cloud system during RICO field campaign and a drizzling stratocumulus cloud boundary layer during ASTEX project. The key thermodynamic and microphysical parameters of the cumulus convective system in RICO simulation matched very well parameters of the benchmark explicit microphysics simulation. The new formulation of autoconversion and accretion rates, and accounting for selfcollection process resulted in a significantly enhanced rain production compared to the KK formulation (Fig. 2). Although our effort focused mainly on deriving new conversion and sedimentation rates for cumulus convective clouds, we also found strong sensitivity to representation of rain evaporation. The accurate formulation of this process tuned for the case of cumulus convection has substantially improved precision of rain production, even when using old KK conversion/sedimentation rates.

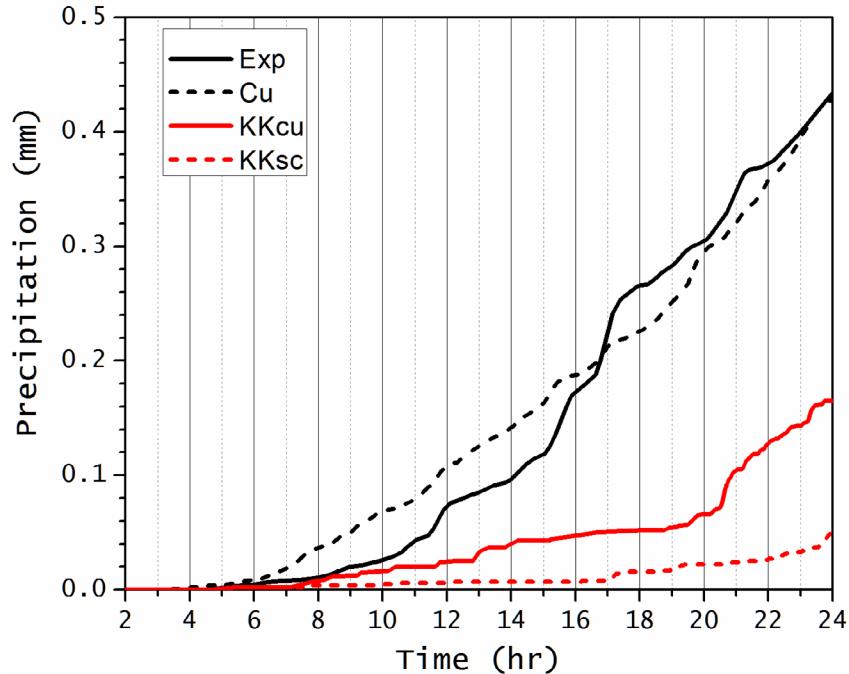


Figure 2. Accumulated precipitation at the surface over the 24 hour simulation. The curves correspond to following model runs: Exp - explicit microphysics, Cu - new cumulus parameterization, KKsc - original Khairoutdinov and Kogan (2000) stratocumulus formulation, KKcu – KK parameterization with cumulus formulation of rain evaporation.

In a simulation of stratocumulus boundary layer cloud case based on ASTEX data, the new parameterization was shown to match quite accurately the performance of the KK parameterization (Fig. 3); thus, the Cu parameterization can be applied for a range of parameters covering both stratocumulus boundary layer and trade wind shallow cumulus convective clouds.

The generalization of the parameterization for meso and large scale models requires supplementing the conversion and sedimentation rates with probability distribution functions of cloud and rain parameters. This task will be the focus of our work in the following years.

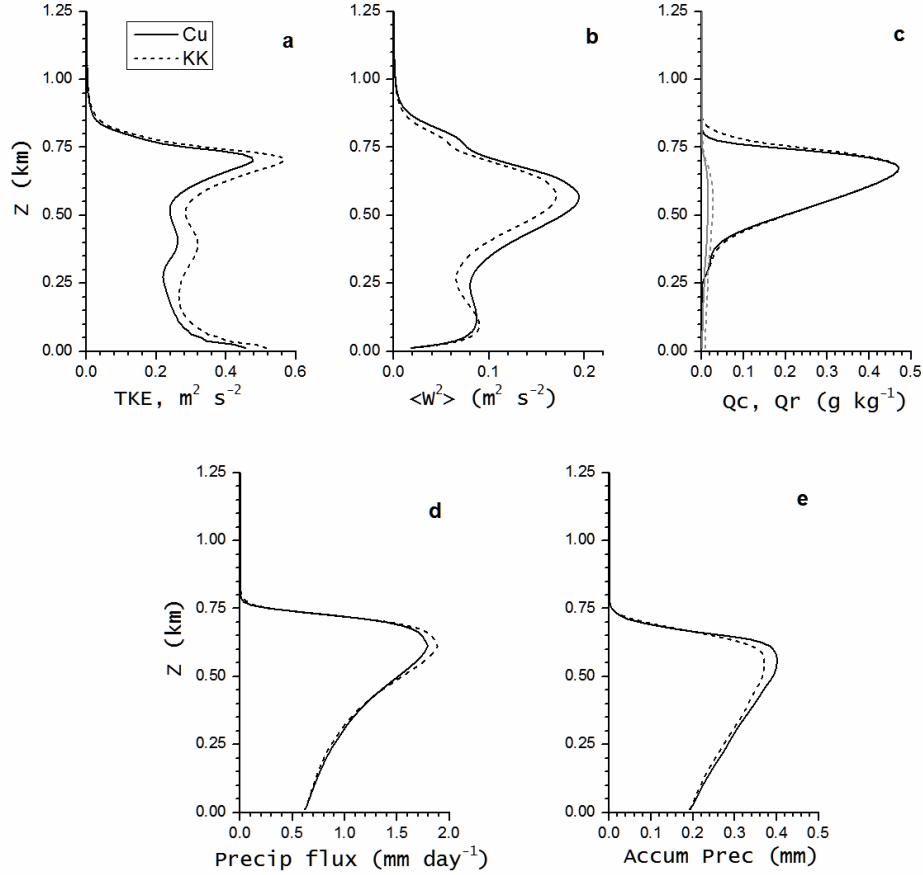


Figure 3. Profiles of horizontal mean parameters averaged over the last hour of the six hour ASTEX simulation. The solid (dashed) lines correspond to simulations using Cu (KK) parameterization; a) turbulent kinetic energy (TKE), b) vertical velocity variance, c) cloud liquid water (black) and rain water (gray), d) precipitation flux, and e) accumulated precipitation.

IMPACT

The improved parameterization of the physical processes in shallow convective cloud systems will lead to more accurate numerical weather predictions for Navy operations.

TRANSITIONS

Our results have been published in three refereed scientific papers and reported at two scientific meetings.

PUBLICATIONS

Kogan Y. L., 2012: A cumulus cloud microphysics parameterization for cloud resolving models. *J. Atmos. Sci.* [Accepted with minor revisions. Referred]

- Kogan, Y.L. and A. Belochitski, 2012: Parameterization of Cloud Microphysics Based on Full Integral Moments, *J. Atmos. Sci.*, **69**, 2229-2242. [Referred]
- Kogan, Y. L., D. B. Mechem and K. Choi, 2012: Effects of Sea-Salt Aerosols on Precipitation in Simulations of Shallow Cumulus, *J. Atmos. Sci.* **69**, 463-483. [Referred]
- Kogan, Y. L., 2012: LES based approach to parameterization of cumulus convective cloud systems, Second Scientific Workshop on ONR DRI “Unified Parameterization for Extended Range Prediction”, NRL-Monterey, July, 2012.
- Kogan, Y. L., 2012: A new parameterization of shallow cumulus clouds in mesoscale models, 1st Pan-GASS Meeting, Boulder, CO, September 10-14, 2012.